CHAPTER 19
ENVIRONMENTAL MANAGEMENT OF EXPLOSIVES

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19 ENVIRONMENTAL MANAGEMENT OF EXPLOSIVES

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19.1 AWARENESS SUMMARY

The training with and, test and evaluation of Weapons, Ordnance, Munitions and Explosives (WOME) involves the release to ground, water and air of chemicals which could potentially have an adverse effect on the environment. Therefore cognisance needs to be taken of the broad legislative framework which governs environmental issues generally, and the way in which this applies from cradle to grave in the WOME life cycle.

Legislation cascades down from international conventions, treaties and protocols, through European directives and regulations to UK law. That legislation is then interpreted by the Ministry of Defence through its various Joint Services Publications.

At the international level there is a fundamental difference between the internationally agreed framework that applies in warfare under the Geneva Conventions and that which applies in peacetime for training, test and evaluation. The Geneva Conventions state that it is prohibited to employ methods or means of warfare which are intended, or may be expected, to cause widespread, long-term and severe damage to the natural environment. In peacetime there are more stringent restrictions, such as the MARPOL Convention which dictates what can be placed in the marine environment and the Oslo Convention which prohibits the dumping of WOME at sea.

At the EU level there is little legislation specific to the environmental consequences of manufacturing, functioning and disposal of WOME, albeit REACH legislation (link to 1.3.2.4.6) does encompass some of the chemicals used in munitions.

UK legislation applicable to WOME includes the Environmental Protection Act of 1990 (EPA90) and the Environment Act of 1995 (EA95). The latter saw the establishing of the Environment Agency as the regulator for England and Wales and the Scottish Environmental Protection Agency for Scotland. Arrangements for Northern Ireland followed later. It deals with the liability for paying for the remediation of land contaminated by past activities of the Ministry of Defence and its predecessor organisations involving the use of WOME. The act also sets out the duty of the MoD toward the National Parks on which the Department does much of its training at locations such as Dartmoor and Otterburn. There are statutory limits on the permissible emissions to air for a range of potential pollutants, these including some of the products of functioning of WOME. The Water Resources Act states that a person contravenes the act if he causes or knowingly permits any poisonous, noxious or polluting matter or any solid waste matter to enter any controlled waters. This is important in the context of training and test and evaluation areas where WOME is used, given the possibility that explosives, heavy metals and the products of functioning of WOME may

migrate into controlled waters such as rivers, lakes and aquifers. The UK does not have threshold levels for explosives in drinking water, but in areas where there is the possibility of contamination from explosives the relevant authority may impose thresholds on nearby watercourses. These may be based on an agreed level, or by comparison with threshold levels imposed by other nations such as the United States.

Most breaches of environmental law are criminal offences. The penalties are usually a fine and/or imprisonment. For cases tried in the Magistrates' court, the maximum penalty is usually a fine and/or six months' imprisonment. In the case of the Crown Court, the maximum penalty is usually an unlimited fine and/or two years imprisonment.

Within Defence the policy relating to environmental protection is set out in Defence Safety Authority publication (DSA 01.1) "Defence Policy for Health, Safety and Environmental Protection", which describes in high-level terms the corporate system for the management of environmental protection and safety in the Ministry of Defence (MOD). Specifically it states that within the United Kingdom the Ministry of Defence will comply with all applicable environmental legislation. When operating overseas the Department will apply UK arrangements where reasonably practicable and, in addition, respond to host nations' environmental expectations. The policy goes on to state that where Defence has exceptions, derogations or dis-applications from environmental legislation, arrangements will be maintained that are, so far as reasonably practicable, at least as good as those required by UK legislation. Various Defence Safety Authority and Joint Services Publications sets out more detailed guidelines for the management of environmental protection in Defence.

The science underpinning the environmental impact of the functioning of explosives and munitions is a complex subject, with many factors contributing to the fate and effects of contaminants on the environment. These include the quantity of contaminant, the source and location of contamination, the local climate and the chemical composition of the munition. Nevertheless general behaviours and impacts of the most common explosive contaminants have been identified. This process is assisted by the use of the source-pathway-receptor (SPR) pollution linkages concept. This describes how a contaminant can enter the environment from a source, such as unexploded ordnance (UXO) or the products of functioning a munition in its design mode, and move through the environment by air, soil or water (pathway) to a receptor, usually defined as an entity that may be adversely affected by contact with a contaminant. A receptor can include flora and fauna, humans, as well as the ecology of an area. The contamination from specific explosives on ranges is highly dependent on the training or test and evaluation activity. For example soil at impact areas is most likely to be contaminated with RDX, HMX and TNT, whereas soil at firing areas is more likely to be contaminated with propellants such as nitroguanidine (NQ) and nitrocellulose (NC). Traces of explosives and degradation products have also found in nearby surface water, and/or groundwater indicating that explosives are able to travel through soil, and in water run-off. The extent to which this occurs depends upon the solubility of the

explosive in water, generally measured in milligrams per litre. Another factor affecting the fate and transport of explosives is the soil sorption coefficient which essentially describes the likelihood of the explosive to bind to soil particles. In both cases, solubilisation in water or binding to the soil, explosives are vulnerable to degradation by bacteria in the soil (biodegradation) or sunlight (photodegradation).

In order to assess the environmental impact of military materiel including WOME, the MOD has developed a bespoke platform known as the Project Orientated Environmental Management System (POEMS), which was designed to facilitate the application of an Environmental Management System (EMS) to specific MOD activities and equipment throughout the life cycle. POEMS is based on the international standards ISO 14001 and ISO 14040, the former representing the cornerstone of EMS and the latter covering life cycle assessment (LCA). POEMS comprises nine core procedures (link to table 19-4).

One of the most important elements of POEMS is Serial 5 - the compilation of an environmental features matrix which ranks the environmental impacts in priority order to determine the most significant ones associated with any activity, each impact being scored in terms of its severity and frequency or duration.

The implementation of POEMS accordingly identifies those environmental impacts that exceed a minimal threshold score and require further investigation in the form of an Environmental Impact Assessment. Two approaches for conducting such an assessment are available; the first involves the bringing together a range of Suitably Qualified and Experienced Personnel (SQEP) who possess (a) a good knowledge of explosives chemistry and (b) have recent and relevant experience of the way in which WOME is used in the field. The second approach involves compiling numerical details of the materials used in a weapon system, and the chemical products of functioning that weapon. These are compared with statutory pollution limits.

A broader range of environmental procedures relevant to the estate and infrastructure is given in The MOD Sustainability and Environmental Appraisal Tools (SEAT) Handbook, which is the single point of reference for the suite of appraisal tool methodologies (link to Table 19-3).

Where explosives are in constant use at a particular location, and pathways to receptors have been identified, it may be necessary to monitor receptors for traces of contaminants. Various sampling techniques are available for such monitoring; for instance multi-increment sampling is a method developed to overcome the difficulties with obtaining representative sample of very large areas of heterogeneously deposited contamination on soil. Instead of taking and analysing discrete samples which represent only a tiny portion of the entire area, multiple samples are taken and combined over several large areas of a range, thus smoothing out the heterogeneities. If significant contamination is identified, then remediation is required. That remediation may be chemical, physical or biological. Chemical remediation techniques include in situ chemical oxidation; physical remediation generally involves disposal of contaminants with

controlled fires, whereas biological remediation is undertaken through plant uptake and concentration of contaminants or metabolism or degradation into less toxic compounds.

Computer models are commonly used to attempt to predict source – pathway - receptor linkages for explosives. Environmental models use mathematical approaches to combine different forms of data, such as toxicological data and characteristics of the environment, into concise information suitable for environmental risk assessment, or to determine contamination levels in an area or environment.

Several countries, including the USA and Norway have developed databases of information for range management. At the current time, the UK does not have an established environmental database for WOME; however relevant research is undertaken when required on a case by case basis.

19.2 ENVIRONMENTAL LEGISLATION AND GOVERNANCE

19.2.1 Introduction

Within this section pertinent legislation is described. It is by no means exhaustive, but rather it is intended to give the reader a broad appreciation of the environmental legislative framework within which the Weapons, Ordnance, Munitions and Explosives (WOME) community must operate. It should be read in conjunction with Chapter 3 (Legislation). The chapter therefore aims to be a starting point for understanding the intricacies of environmental legislation and to guide the reader towards the legislation of relevance.

There is a legal requirement for all businesses, organisations and government departments to manage their environmental impacts. The MOD is not exempt from such legislation. Non-compliance with environmental law risks legal action which may include prison sentences or financial penalties. But beyond the legal compliance there are other benefits of compliance such as improved public perception, and financial gains due to reduction in energy use and waste production.

19.2.2 The Evolution of Modern Environmental Legislation

There is a hierarchy of legislation cascading down from international treaties and conventions through European legislation to UK law, which is then reflected in Defence-specific arrangements. These arrangements are illustrated in Figure 19-1.

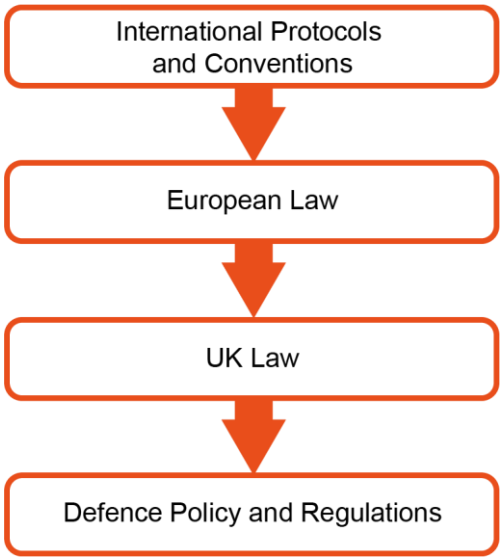

Figure 19-1 Hierarchy of legislation

19.2.3 International Environmental Legislation

International law is self-enforced by agreement to a treaty, also known as protocols, conventions and agreements. International Treaties seek to regulate issues as diverse as Climate Change, Ozone Depleting Substances (ODS) and International Waste Shipments as well as explosive governance in conflict situations and training.

19.2.4 Geneva Convention

Under International Humanitarian Law the United Kingdom is legally obliged to ensure that all weapons and associated equipment that it obtains, plans to acquire, or develops, comply with the UK's treaty and other obligations. This legal review process is mandated by Article 36 of The First Protocol of 1977 additions to the Geneva Conventions of 1949 (Additional Protocol I), which is the section on 'Methods and Means of Warfare', and to which the UK is a Party. Article 36 states:

"In the study, development, acquisition or adoption of a new weapon, means or method of warfare, a High Contracting Party (i.e. the UK) is under an obligation to determine whether its employment would, in some or all circumstances, be prohibited by this Protocol or by any other rule of international law applicable to the High Contracting Party."

Article 35 of the 1977 Additional Protocol I of the Geneva Conventions 1949 states that:

"It is prohibited to employ methods or means of warfare which are intended, or may be expected, to cause widespread, long-term and severe damage to the natural environment." MOD interpretation of Article 35 is that serious damage is caused to flora and fauna over tens of square kilometres lasting tens of years.

Article 55 of the 1977 Additional Protocol I of the Geneva Conventions 1949 states that:

"Care shall be taken in warfare to protect the natural environment against widespread, long-term and severe damage. This protection includes a prohibition of the use of methods or means of warfare which are intended or may be expected to cause such damage to the natural environment and thereby to prejudice the health or survival of the population."

A legal review is required to be undertaken to determine the legality of the use of military equipment in the context of international armed conflict. This review does not cover any domestic use of the equipment (i.e. within the UK). The process for the latter is explained in JSP 520 "Safety and Environmental Management of Ordnance, Munitions and Explosives over the Equipment Acquisition Cycle" Part 2 "Guidance", Vol 7 "Legislation Compliance".

Legal reviews are conducted on behalf of the MOD by the Legal Team at the Development, Concepts and Doctrine Centre (DCDC) at Shrivenham to whom all queries about the necessity or conduct of a legal review should be addressed. It should be emphasised that the Geneva Conventions only apply during armed conflict.

19.2.5 Training

When training is taking place in either the UK or overseas, much more stringent regulations apply. If the training is on land, then the host nation's legal framework applies and in most Western nations this is very rigorous.

If the training is at sea, then the International Convention for the Prevention of Pollution from Ships, 1973 as modified by the Protocol of 1978, known as the MARPOL (marine pollution) Convention, applies. MARPOL has six Annexes covering pollution by oil, noxious liquids, packaged harmful substances, sewage and garbage, also air pollution from ships.

19.2.6 Sea Dumping

Historically large quantities of OME were disposed of by sea dumping, much of this being after the Second World War. Estimates suggest that in excess of one million tonnes of munitions were dumped in Beaufort's Dyke in the Irish Sea between Scotland and Northern Ireland. This is a very deep trench, and in principle it should have been a safe place to dump munitions, but in practice many have subsequently been washed ashore, with some consequent injuries. Most probably this is because the ships which were tasked with dumping the munitions in the deep trench did not go far enough off-shore and left them in shallow waters, indeed anecdotal evidence supports this hypothesis, but there remains a degree of uncertainty over this. In addition some 168,000 tonnes were dumped in Skagerrak and some 300,000 tonnes in the North Sea. There are some 148 individual dumpsites spread from Iceland to Gibraltar as shown in Figure 19-2.

In 1972 The Oslo Convention for the prevention of Marine Pollution by dumping from ships and aircraft heralded the end of the practice. Dumping by the UK finally ceased in 1973 prior to the ratification by the Government of the Convention in 1975. This was later subsumed Into Convention for the Protection of the Marine Environment of the North-East Atlantic – the OSPAR Convention which was concluded in Paris on 22nd September 1992. This latter Convention entered into force on 25th March 1998.

It should be noted that, for the purpose of the Convention, "dumping" does not include “placement of matter for a purpose other than the mere disposal thereof, provided that such placement is not contrary to the aims of this Convention”. Therefore the firing of munitions from land, ships and aircraft into the sea is allowable both for training and Test & Evaluation (T&E) purposes.

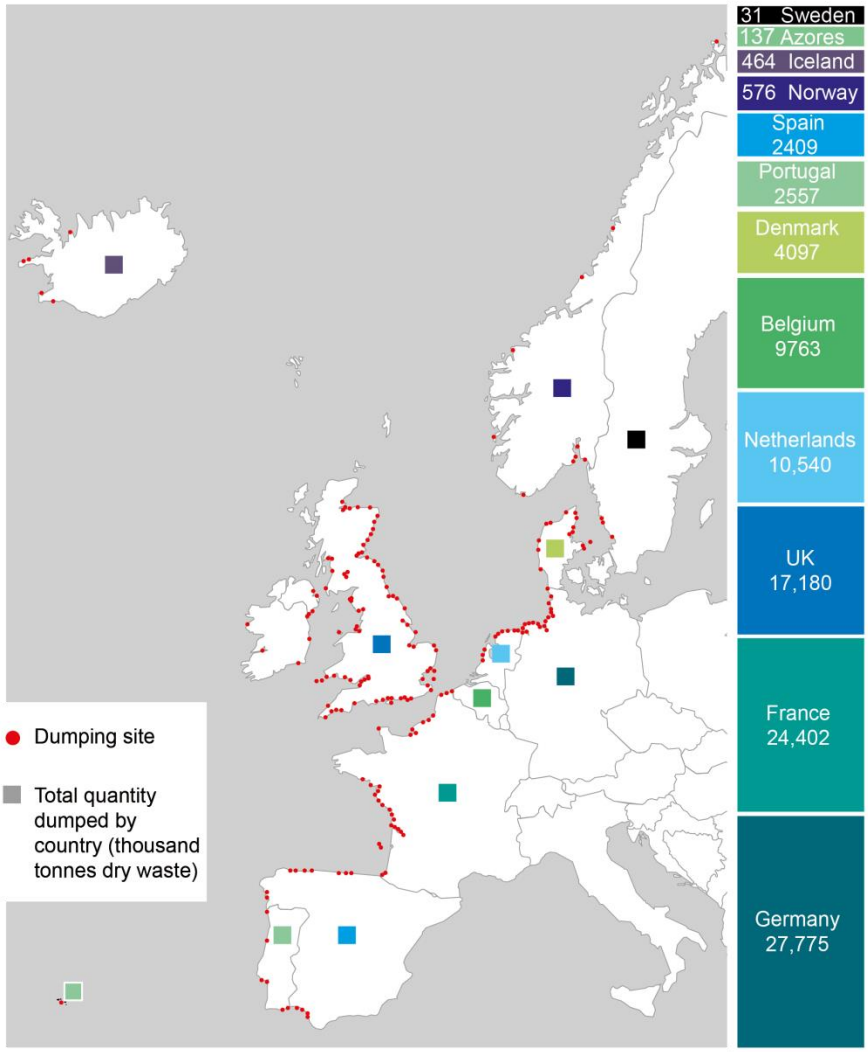

Figure 19-2 Sea dumping locations and quantities by country

19.2.7 European Environmental Law

At the time of writing the UK has voted to leave the EU and has invoked Article 50 of the Lisbon Treaty which triggered the withdrawal process. The terms of the interface arrangements with the EU after this has taken place have yet to be determined, and hence the requirement or otherwise to align UK legislation to EU Directives. In the interim a Repeal Act will transpose EU legislation into UK law pending determination as to whether EU Directives, etc. should in future remain part of UK legislation.

Since the UK joined the European Community in 1972 up until the UK referendum voted to leave the EU, European environmental legislation has increasingly shaped most domestic environmental laws. In turn European legislation has frequently been informed by international Protocols and Conventions. European law falls into a number of categories:

- Regulations are directly applicable laws in all member states
- Directives are legally binding documents which specify desired outcomes or objectives and specific dates for achievement of those outcomes. They leave the means of achieving the objectives to national governments.
- Decisions are directed at specific aspects and are legally binding on specific persons/institutions/procedures but are not generally applicable.
- Recommendations and Opinions are produced by the EU Parliament by the various committees and are not legally binding.

A series of single issue Directives were initially made but these have increasingly been replaced by “Framework” and “Daughter” directives. The aim of Framework Directives is to take a more integrated approach to environmental protection.

The Single European Act of 1986 requires under Article 130R that all policies of the EU should contain a component for environmental protection:

- Article 130R(1) covers measures to preserve, protect and improve the environment, to protect human health and to ensure utilisation of natural resources.
- Article 130R(2) embraces the principle of preventative action, that environmental damage should be corrected at source as a priority and that the polluter should pay.
- Article 130R(4) covers the "subsidiarity principle", that is that the EU should only take action when the objectives could be better achieved at community rather than national level

There are a number of EU Directives relating to OME, for instance Directive 2014/28/EU of the European Parliament and of the Council dated 26 February 2014 relates to the harmonisation of the laws of the Member States relating to the making available on the market and supervision of explosives for civil uses. There is, however, little EU legislation specifically referring to OME and the environment.

19.2.8 UK Environmental Legislation

There are three legal systems in the UK for England and Wales, Northern Ireland and Scotland. UK law comprises two elements; criminal and civil. Criminal is the body of law that deals with criminal offences. This may take the form of Statutes or Acts of Parliament. It may be delegated legislation such as Enabling Acts. It may also be through the mechanism of Statutory Instruments. Civil law governs relations between individuals or disputes between two parties.

19.2.9 Environmental Legislation Relevant to Activities involving Explosives

The principal UK legislation covering explosives is contained in the Explosives Regulations 2014 and the Pyrotechnic Articles (Safety) Regulations 2015. These are principally focussed on the safe use of explosives and pyrotechnics, and make no specific reference to the environment. Explosives legislation is covered in detail in Chapter 3. There is, however, much legislation which relates to and controls the use of OME. Arguably the two most important Acts of Parliament on environmental protection are the Environmental Protection Act of 1990 (EPA90) and the Environment Act of 1995 (EA95). EPA90 comprises seven parts:

1. Integrated pollution control
2. Waste on land
3. Statutory nuisance
4. Litter
5. Radioactive substances
6. Genetically modified food
7. Nature conservation

Of these, 1, 2, 3, 4, and 7 are pertinent to the functioning of OME on training and Test & Evaluation ranges. Statutory nuisance in this context includes noise and the creation of smoke and dust clouds.

EA95 expanded upon EPA90 and saw the establishing of the Environment Agency as the regulator for England and Wales and the Scottish Environmental Protection Agency for Scotland Arrangements for Northern Ireland followed later. EA95 covered other issues such as:

1. Contaminated land
2. National waste strategy
3. National parks
4. Air quality strategy
5. Minerals planning and abandoned mines
6. Water pollution measures
7. Statutory nuisance in Scotland

All of these with the exception of (5) are relevant to the functioning of OME.

EPA90 and EA95 brought together a range of earlier laws into a coherent whole, and subsequently more specific legislation on the various subject areas emerged.

Three areas within EA95 need explanation in terms of their relevance to OME use on training ranges.

19.2.9.1 Land contamination

EPA90 Part IIA provides the regulatory regime for the identification and remediation of contaminated land. EA95 Section 57 contains the provisions, which make up Part IIA of EA90, setting out a new regime for the identification and remediation of contaminated land. The Contaminated Land (England) Regulations (2006) under

DEFRA Circular 01/2006 “Contaminated Land” provides details of the provisions including the definition of contaminated land, identification and remediation; also the liability for who pays for remediation. There is a substantial legacy issue associated with contaminated land arising from the past activities of the Ministry of Defence and its predecessor organisations involving the use of OME.

19.2.9.2 National Parks

Over two thirds of the 240,000 hectares of land owned by the MOD is held for the purpose of training the armed forces. This land is the Defence Training Estate, and comprises 16 major armed forces training areas, and 104 other minor training areas, ranges and camps. Some of this estate is on National Parks, for instance Dartmoor and Otterburn, and significant precautions have to be taken to ensure that training activities do not conflict with the purpose of the parks.

The aims and purposes of National Parks are laid out in law in the form of the 1949 National Parks and Access to the Countryside Act.

There are slightly different aims and purposes for the national parks in Scotland and for the Broads National Park, compared to other national parks in England and Wales. When the aims and purposes conflict with each other, then the “Sandford Principle” is used to give more weight to conservation of the environment.

EA95 revised the original legislation and set out two statutory purposes for national parks in England and Wales:

- Conserve and enhance the natural beauty, wildlife and cultural heritage
- Promote opportunities for the understanding and enjoyment of the special qualities of national parks by the public

When national parks carry out these purposes they also have the duty to seek to foster the economic and social well-being of local communities within the national parks.

The 21st century brought two Scottish National Parks into existence, the Cairngorms and Loch Lomond & the Trossachs, created by the National Parks (Scotland) Act 2000. In 2005, the New Forest finally joined the National Park 'family'. The South Downs was established on 31 March 2010, and became fully functioning, including becoming the planning authority for the National Park, on 1 April 2011.

The duty of the MoD toward National Park purposes is set out in S62 (2) of the Environment Act 1995 and the Government Policy on Military Activity in National Parks in Circular 12/96. A Declaration of Intent between The Ministry of Defence and the Association of National Park Authorities (NPAs) has been established. The Declaration aims to set a framework for maintaining and enhancing working relationships between the MoD and the NPAs and its landlords and relates to any areas subject to MOD training or other rights in areas located in National Parks in Great Britain. The functioning of OME on the National Parks is necessarily a sensitive issue, and, quite apart from the need to operate legally, there are reputational issues to be considered.

19.2.10 Air Quality

Statutory Instrument 2010 No. 1001 “Environmental Protection - The Air Quality Standards Regulations 2010 came into force on 11th June 2010 These set statutory limits for emissions to air as shown in

Table 19-1.

In practice these limits are set for continuous or semi-continuous processes such as vehicle and industrial plant emissions and are very unlikely to be exceeded by the functioning of OME. In the UK the most relevant examples of a trial whereby there were likely to be longer term emissions were the disposal at the Shoeburyness Test & Evaluation range of 120,000 Barmines by open burning and the disposal at the same range of mixed natures of OME, also by open (cage) burning. Measurements of the resultant levels of atmospheric pollutants showed that natural dispersion rapidly reduced the concentrations to well below the statutory limits. Nevertheless, if calculations or measurements show that the statutory limits are being approached, then mitigation measures need to be put into place.

Table 19-1 Statutory Limits for Emissions to Air

Pollutant	Averaging period	Limit value
Sulphur dioxide	One hour	350 µg m^{-3} not to be exceeded more than 24 times a calendar year
	One day	125 µg m^{-3} not to be exceeded more than 3 times a calendar year
Nitrogen dioxide	One hour	200 µg m^{-3} not to be exceeded more than 18 times a calendar year
	Calendar year	40 µg m^{-3}
Benzene	Calendar year	5 µg m^{-3}
Lead	Calendar year	0.5 µg m^{-3}
PM_{10} (particulate matter which passes through a size-selective inlet with a 50 % efficiency cut-off at 10 µm aerodynamic diameter).	One day	50 µg m^{-3}, not to be exceeded more than 35 times a calendar year
	Calendar year	40 µg m^{-3}
Arsenic	Target value for the total content in the PM10 fraction averaged over a calendar year	6 ng m^{-3}
Cadmium		5 ng m^{-3}
Nickel		20 ng m^{-3}
Benzo(a)pyrene		1 ng m^{-3}
$PM_{2.5}$ (particulate matter which passes through a size-selective inlet with a 50 % efficiency cut-off at 2.5 µm aerodynamic diameter).	Calendar year	25 µg/ m^{-3}
Carbon monoxide	Maximum 8 hour daily mean	10 mg m^{-3}
Ozone	Maximum daily 8 hour mean	Target value 120 µg m^{-3} not to be exceeded on more than 25 days per calendar year averaged over three years

Table 19-2 Water and Soil Threshold levels for Common Explosives

Explosive/ degradant	Drinking water threshold µg L^{-1}	Recommended soil threshold mg kg^{-1}	Source
2,4-Dinitrotoluene (DNT)	100	1.6 (residential) 5.5 (industrial)	United States Environmental Protection Agency (DNT)
2,6- Dinitrotoluene (DNT)	40	0.3 (residential) 1.2 (industrial)	2012 Drinking Water Standards and Health Advisories tables
HMX	100	N/A	ATSDR factsheet
Nitrocellulose	Not considered toxic		
Nitroglycerine	Unregulated, but considered a candidate contaminant		EPA Drinking Water Contaminant List
Nitroguanidine	3500		2012 Drinking Water Standards and Health Advisories tables
Perchlorate	Drinking water: 1-18 Groundwater: 1-72	55 (residential) 720 (industrial)	US EPA Technical Factsheet
RDX	100	N/A	ATSDR factsheet
Trinitrotoluene (TNT)	20	19 (residential) 79 (industrial)	United States Environmental Protection Agency (TNT)

19.2.11 Water Pollution Measures

The Water Resources Act 1991 Chapter 57 “Offences of polluting controlled waters” states that *“a person contravenes this section if he causes or knowingly permits any poisonous, noxious or polluting matter or any solid waste matter to enter any controlled waters”*. ‘Causing' means not only deliberately releasing any polluting matter but also causing the pollution accidentally, by being the operator of a plant or process. “Controlled waters” in this context means any river, lake, pond or aquifer. The Water Act 2003 Chapter 37 “Contaminated land: pollution of controlled waters” amends the definition of "contaminated land" in Section 78A of the Environmental Protection Act 1990 so that it applies only where significant pollution of controlled waters is being caused, or there is a significant possibility of such pollution being caused. These Acts are important in regard to training areas where OME is used, given the possibility that explosives, heavy metals and the products of functioning of OME may migrate into controlled waters. An example is the Central Impact Area in the Salisbury Plain Training Area. This lies over an aquifer from which the drinking water for the city of Salisbury is extracted.

The UK does not have threshold levels for explosives in drinking water, but in areas where there is the possibility of contamination from explosives the relevant authority may impose thresholds on nearby watercourses. The threshold limits imposed may be based on an agreed level or by comparison to threshold levels imposed by other nations. Table 19-2 gives water and soil threshold levels for common explosives as recommended by the United States Environmental Protection Agency where UK figures are not available.

19.2.12 Penalties for Breaches of Environmental Law

Most breaches of environmental law are criminal offences. The penalties are usually a fine and/or imprisonment. For cases tried in the Magistrates’ court, the maximum penalty (2017) is usually a fine of £20,000 or £50,000 and/or six months’ imprisonment. In the case of the Crown Court, the maximum penalty is usually an unlimited fine and/or two years imprisonment. The main environmental regulators in England are the Environment Agency (EA) and local authorities, and Natural Resources Wales in Wales. The Scottish Environment Protection Agency (SEPA) is Scotland's principal environmental regulator. Northern Ireland Environment Agency (NIEA), which is part of Northern Ireland Executive's Department of Environment, is Northern Ireland's environmental regulatory body. Environmental regulators can, in some cases, serve an enforcement notice on a business requiring it to rectify a breach of environment law. The regulator may also have the power to order the closure or suspension of the business until the breach has been rectified. Breach of any of these types of notice is a criminal offence. Environmental regulators can, in some cases, serve a notice on a business requiring it to clean up any contamination, including water pollution, they have caused. Breach of this type of notice is a criminal offence. The regulators can also prosecute the business’ directors, managers, secretary or other similar officers or person purporting to act in any such capacity, if it can be shown the offence was committed with their

consent or connivance, or was attributable to their neglect. New legislation has given regulators, including the EA and local authorities, the power to impose civil penalties on businesses, as an alternative to prosecuting, for certain types of breaches, including breaches of environmental legislation. Civil penalties include fixed monetary penalties and enforcement undertakings. The civil penalties approach is more flexible and designed to fit the penalty more appropriately to the crime. It frees resources for criminal prosecutions while removing the burden from respectable companies that make a low level breach of regulations and raises the penalties for people who carry out deliberate environmental crimes.

19.3 DEFENCE POLICIES AND REGULATIONS

Within Defence the policy relating to environmental protection is set out in Defence Safety Authority publication (DSA 01.1) “Defence Policy for Health, Safety and Environmental Protection”, which describes in high-level terms the corporate system for the management of environmental protection and safety in the Ministry of Defence (MOD). It states that the MOD has as a fundamental objective to protect the environment when undertaking all defence activities. This includes the use, transport and destruction at end of life of explosives where there is potential for interaction with and contamination of the environment. Specifically it spells out the Secretary of State’s policy on environmental protection as follows:

1. Within the United Kingdom the Ministry of Defence will comply with all applicable environmental legislation.
2. Overseas the Ministry of Defence will apply UK arrangements where reasonably practicable and, in addition, respond to host nations’ environmental expectations.
3. Where Defence has exceptions, derogations or dis-applications from environmental legislation, arrangements will be maintained that are, so far as reasonably practicable, at least as good as those required by UK legislation.

More specific directions and guidance are given in Joint Services Publication (JSP) 418 “Management of Environmental Protection in Defence”.

JSP418 sets out guidelines for the management of environmental protection in defence and states that all MOD sites should be covered by an Environmental Management System (EMS). Part 2 of JSP 418 “Guidance” contains a series of leaflets 01 – 07 as shown in Table 19-3. Leaflets 01 – 05 are particularly relevant to the environmental impact of OME.

It is also MOD policy that all new acquisition projects must have a safety and environmental management system that defines the environmental impact of the acquisition throughout the lifecycle. The MOD procedures for ensuring that this takes place are in the Project Oriented Environmental Management System (POEMS). Further details of POEMS are given in Section 4 of this chapter. The specific application of an Environmental Management System to OME is described in in JSP520 (part 2, volume 3) – “Safety and Environmental

Management of Ordnance, Munitions and Explosives (OME) over the Equipment Acquisition Cycle".

A broader range of environmental procedures relevant particularly to the estate and infrastructure is given in The MOD Sustainability and Environmental Appraisal Tools (SEAT) Handbook, which is the single point of reference for the suite of appraisal tool methodologies used on Estates related plans, programmes projects and activities such as military training within MOD. This contains eight Sections as shown in Table 19-4. Sections 2, 4 and 5 are particularly relevant to the environmental impact of OME.

Table 19-3 JSP 418 Guidance Leaflets

Document	Title
Leaflet 01	Environmental Management Systems
Leaflet 02	Pollution Prevention
Leaflet 03	Controlled Waste
Leaflet 04	Statutory Nuisance
Leaflet 04-1	Environmental Noise
Leaflet 05	Hazardous Substance and Restricted Materials
Leaflet 06	Fluorinated Greenhouse Gases
Leaflet 07	Ozone Depleting Substances

Table 19-4 MOD Sustainability and Environmental Appraisal Tools Handbook Sections

Document	Title
Section 1	Summary Booklet
Section 2	Sustainability Appraisal
Section 3	Strategic Environmental Assessment
Section 4	Environmental Impact Assessment
Section 5	Habitats Regulation Assessment
Section 6	Defence Related Environmental Assessment Method (DREAM)
Section 7	Climate Impacts Risk Assessment Method (CIRAM)
Section 8	Linked Tools

19.4 ENVIRONMENTAL SCIENCE OF EXPLOSIVES

19.4.1 Introduction

Many factors contribute to the fate and effects of contaminants in the environment such as the quantity of contaminant, the source of contamination, the location of contamination, the local climate and the chemical composition of the contaminant. It is impossible to predict the environmental impact of any one explosive in a given environment; however general behaviours and impacts of the most common explosive contaminants have been identified. Contaminated areas, and most likely transport pathways can also be established through a combination of site and literature knowledge and, if possible, computer modelling techniques. Armed with this knowledge, it is possible to determine when monitoring (section 19.6) or remediation (section 19.7) activities would be necessary, and which methods it would be appropriate to use.

The aim of this section is to give an overview of the complex environmental interactions and processes that contribute to the transport of explosive contaminants through the environment and the potential impact of specific explosives on the environment.

19.4.2 Source-Pathway-Receptor Pollution Linkages Model

One of the most useful ways to describe the fate and transport of contaminants in the environment is using the source-pathway-receptor (SPR) pollution linkages concept. It describes how a contaminant can enter the environment from a source, such as unexploded ordnance (UXO), and move through the environment by air, soil or water (pathway) to a receptor, usually defined as an entity that may be adversely affected by contact with a contaminant. An ‘entity’ can include flora and fauna, humans, as well as the ecology of an area such as a lake, or a Site of Special Scientific Interest (SSSI). For example, explosive residue from a damaged UXO (source) may be dissolved in water from rainfall and transferred into the soil. The explosive may then travel through the soil until it reaches an underground aquifer. In an isolated incident the concentration of explosive would be undetectable and in most cases would be unlikely to affect a receptor. However, if contamination from explosive residue is a frequent occurrence the quantities reaching groundwater may become significant and affect humans using the aquifer as a potable water source, or even contaminate downstream rivers or lakes and affect local flora and fauna populations (Figure 19-3).

The point at which a contaminant reaches and affects a receptor is when the contaminant can be said to cause an environmental impact. If the SPR linkages between the source and receptor are broken at any point then no environmental impact will be observed, that is, if the contaminant does not reach a receptor. When considering explosive contaminants in the context of the MOD the most likely source of contamination is from munitions containing explosives, and the most likely means by which explosives enter the environment is through training or Test & Evaluation activities on ranges. Therefore much of the following

discussion will focus on the environmental impact of explosives on such ranges; however the underlying environmental science would be applicable to explosive contamination at any site.

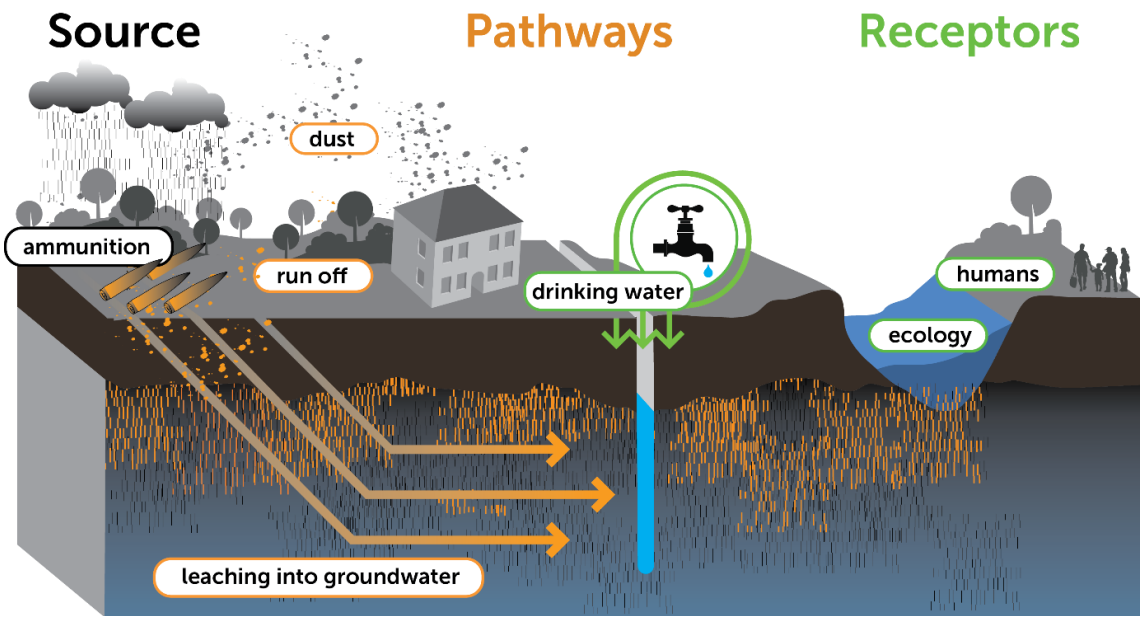

Figure 19-3 A schematic showing some potential source-pathway-receptor linkages model for unexploded ordnance on a range (Courtesy of Cranfield University)

The SPR concept should be used in risk assessments to link contaminant sources to potential exposure routes. The degree of risk to a receptor depends on the amount and frequency of contaminant exposure[1]. For explosives the most common route for transport in the environment is through soil and water as any particulates released into the air are likely to fall back to the ground in close proximity to the site where the explosive initiated. Small isolated quantities of explosive residue that are carried further are unlikely to cause significant environmental impact. For explosives, contamination is usually due to the cumulative build-up of residue in areas of long-time explosive use, such as impact sites. Thus, when assessing munitions or explosives for environmental impact it is important to account for the cumulative impact of multiple detonations in specific locations.

19.4.3 Explosive Contamination on Ranges

19.4.3.1 Common explosive contaminants

Studies conducted at over 30 different military installations in the United States have demonstrated that explosive contaminants are present in surface soils on training ranges[2]. These findings contradicted the long-time assumption that 99.99 % of the energetic material in munitions is consumed in the firing or detonation process. However, the baseline figures were determined by physical and chemical modelling on the assumption that all detonations are high-order. More recent research has shown that although high-order detonations do

almost completely consume the explosive materials, there are also a small percentage of munitions that do not undergo a high-order detonation when fired. In cases where detonation is not high-order, it has been shown that unconsumed explosive material may be scattered unpredictably on the soil as particulate residue[2–5]. It has also been recognised that sympathetic detonation of UXO can result in high quantities of explosive residue in the environment. In some cases munitions may become buried, and subsequently damaged leading to exposure of the explosive filling to the environment[6,7]. Finally, the destruction of end-of-life or damaged munitions through open burning or open detonation can leave high quantities of explosive and propellant residues at the burning ground.

The contamination from specific explosives on training ranges is highly dependent on the training activity. For example soil at impact areas is most likely to be contaminated with RDX, HMX and trinitrotoluene (TNT), whereas soil at firing areas is more likely to be contaminated with propellants such as nitroguanidine (NQ) and nitrocellulose (NC). There may also be traces of lead at the firing area. In most cases, soil has also been found to be contaminated with by-products of the explosives and propellants generated by biological or physical degradation. Traces of explosives and degradation products have also found in nearby surface water, and/or groundwater indicating that explosives are able to travel through soil, and in water run-off[8, 9].

Given the ability of explosives to travel sometimes significant distances in the environment it can be difficult to establish the source of the contamination, and even harder to determine the transport pathway. Transport in the environment is mainly determined by the chemical composition of the explosive combined with the local geology and climate[10]. Highly water soluble explosives could dissolve in rain water and enter the soil very quickly in wet climates, but if the explosive also tends to be absorbed by soil it will not travel much deeper than the surface. Extensive research has been conducted on the oldest and most common explosives and is discussed in the following sections, however it must be remembered that the environmental impact of a specific explosive depends, not only on its chemical properties, but also on the local climate and geology which are extremely variable. Therefore, whilst general trends can be established based on a wide range of global scientific research the effects of explosive contamination on the environment are likely to be unique to a particular location.

19.4.4 Fate and Transport of Common Explosive Contaminants

This section concerns the fate and transport of explosives in the environment, and the impact on environmental receptors including plants and animals.

There are several comparable properties of explosive behaviour in soil that allow some generalisations to be made about their environmental impact. Particularly significant is the solubility of the explosive in water, generally measured in milligrams per litre, literally meaning the maximum mass of explosive possible to dissolve in a litre of water at ambient temperature (20 °C unless otherwise stated).Solubility is important because it is the most likely

route for transport of explosives into groundwater and uptake by plants. Transport of explosives in water can be prevented if the explosive has a high soil sorption coefficient (K_{oc}), or in other words, a high likelihood of binding to soil particles. In both cases, solubilisation in water or binding to the soil, explosives are vulnerable to degradation by bacteria in the soil (biodegradation) or sunlight (photodegradation).

The potential of an explosive to bind to soil is dependent on the nature of the explosive, that is, it must contain appropriate chemical groups, usually nitro or amino groups, and on the soil type. Soils tend to be characterised according to the predominant particle size distribution within a sample and can be split into clay, loam or sand types. However, for sorption of explosives the most significant factor is thought to be the organic content (OC) which describes the percentage of living or decomposing matter in the sample.

19.4.4.1 Nitramines RDX and HMX

RDX and HMX are both nitramines with similar chemical structures, it follows that their properties in the environmental are also similar. HMX is less soluble than RDX (5-6.63 mg L^{-1} and 38.4 mg L^{-1} respectively at 20-25 °C), and solubility of both explosives increases with temperature. RDX (K_{oc}: 0.84-2.2) and HMX (K_{oc}: 0.54) do not sorb significantly to soil, but do tend to sorb more readily to soil with a higher OC[11]. Due to their low sorption to soil RDX and HMX are able to reach sources of groundwater in significant concentrations i.e. concentrations greater than threshold levels[12].

HMX can be photodegraded within a week forming nitrates, nitrites and formaldehyde. RDX can degrade into a variety of compounds in the environment such as methylenedinitramine and nitrodiazabutanal. It is worth noting that there have been far fewer studies into the fate and transport and environmental impact of these degradation products. However, due to the number of degradation products the concentrations of individual species are much lower than the initial concentration of RDX and may not be significant in all areas[13].

Of the two compounds, RDX tends to present more of a problem on training ranges due to its use in large quantities in munitions.

19.4.4.2 Trinitrotoluene

TNT is usually found as a crystalline solid in surface soils. It is soluble in water (130 mg L^{-1} at 20 °C), and tends to sorb to soil. If TNT not sorbed by soil it tends to be rapidly biodegraded into dinitrotoluene (DNT) and isomers of aminonitrotoluene and diaminonitrotoluene, therefore very little TNT tends to reach groundwater. If TNT is washed into surface water it can be degraded by sunlight (photodegradation) to give trinitrobenzene (TNB). High concentrations of TNT in surface water can be identified by a tell-tale pink tint, although contamination of that level is unexpected outside of manufacturing and processing plants[14]. TNT is commonly found on the soil surface at ranges suggesting that the deposition rate is faster than the biodegradation and

dissolution rates. TNT can be taken up by plants and tends to be metabolised quickly, such that bioaccumulation in higher mammals is not expected.

19.4.4.3 Propellants: nitrocellulose, nitroglycerine, nitroguanidine, dinitrotoluene, perchlorates

Propellants tend not to be completely consumed during burning and particles of unburnt propellant are deposited on the range, particularly around the firing areas[2]. Studies on several ranges in the US have found high concentrations of nitroglycerine (NG), nitroguanidine (NQ), perchlorates and dinitrotoluene (DNT) [15]. Although nitrocellulose is a commonly used propellant its presence on firing ranges has not been extensively investigated as it tends to be deposited as discrete fibres which are difficult to quantify. An added complication is the tendency for other explosives to sorb onto nitrocellulose, and so areas where high quantities of NC propellants are in use may be difficult to analyse[16].

NC is insoluble in water and therefore tends to be deposited on the soil surface in fibrous strands, rather than particles. However, NC is bio- and photodegradable. NC undergoes biodegradation to a non-energetic polymer through the loss of nitrogen[16]. NC is not toxic towards humans, animals or plants due to the difficulty of absorption through the intestines and insolubility in water [17]. Deposition of NC on ranges does not have a significant environmental impact on receptors, other than an unnatural presence in the environment.

NG is soluble in water, and does not tend to sorb significantly to soil so it is quite mobile in soil environments[16]. Under favourable soil conditions NG undergoes several stages of biodegradation and can ultimately form glycerol, and in some cases carbon dioxide. However, not all NG will be completely biodegraded, and in sandy soils where attenuation is poor it is unlikely that NG will be significantly biodegraded before migration to ground water[18]. Photodegradation of NG occurs more quickly when it is solubilised in water on the scale of weeks, rather than months. Some degradation products are more toxic than NG, therefore if NG contamination is suspected it is recommended that samples are also tested for mono and di-nitroglycerine [19].

NQ is fairly water soluble (2.6 g L^{-1}) and does not sorb significantly to soil. NQ has been found to be biodegraded in some soils giving ammonia and nitrous oxide particularly in soils with high organic carbon content but it may migrate too quickly through soil for any significant degradation to occur before reaching ground water[20]. Photodegradation of NQ gives guanidine, ureas and cyanoguanidine.

Perchlorate is a naturally occurring and man-made anion that contains one chlorine atom bonded to four oxygen atoms (ClO_4^-). It is commonly produced when energetic compositions in the form of ammonium perchlorate (AP), sodium perchlorate and potassium perchlorate dissolve in water. Perchlorates are generally soluble and stable in water and do not sorb significantly to soil therefore have a great potential to contaminate surface and ground water, and in fact there are well documented incidences of significant ground water contamination from military use of perchlorates[9, 21]. A risk assessment of UK

use of perchlorate highlighted that monitoring for AP in potable water sources is not widespread in the UK, but that high levels of AP were detected in the groundwater at Shoeburyness disposal range where 14.5 tonnes of propellant have been disposed of since 1993[22]. While drinking and ground water limits have not been set for the UK, where contamination has occurred the UK uses the limit of detection (1 µg L^{-1}) as an indication of acceptable levels. The presence of perchlorate in drinking water is a particular concern as it is known to cause abnormal thyroid function in humans[23, 24].

19.4.4.4 Primary explosives and less commonly used secondary explosives

Primary explosives, used in fuzes, and other less common secondary explosives are less frequently found in samples taken from training ranges. Primary explosives are used in very small quantities, and are typically completely consumed on initiation leaving only by-products of the explosive reaction, such as lead in the case of residue from lead azide and lead styphnate.

Tetryl (2,4,6-trinitrophenylmethylnitramine), a warhead booster explosive, was employed extensively in UK service munitions. It has been obsolete for some time, however, it can still be found in surface soil on UK ranges.

19.4.4.5 Pyrotechnics

Pyrotechnics can have a variety of uses from primer compositions to ignite gun propellants to heat, light and noise generating effects[25]. In order to achieve these affects metals are often added to the compositions. Metals most commonly used include aluminium, magnesium, zinc, barium, chromium and lead[26]. Metals do not biodegrade, and can therefore remain in the environment for very long periods of time. However, current research indicates that the concentrations of metal deposits are very low, even for devices initiated on the ground. For airborne devices the metal particulates are distributed by air currents over very wide areas, diluting their presence in the environment. For metal contamination from pyrotechnics to be a significant problem hundreds of firings must take place in the same area[26] or large quantities being subject to disposal by open burning.

Pyrotechnics contain a wide range of chemicals to produce their effects including not only the metals listed above but also a range of oxidisers. These can include nitrates, chlorates and perchlorates, the environmental impact of the latter[27] having been considered earlier (19.4.4.3). White phosphorus used to be widely used as an obscurant in pyrotechnics[28], but is known to be highly toxic and in one well documented case at a military training range in Alaska it was directly responsible for the death of thousands of waterfowl[29, 30]. Ingesting even a small amount of white phosphorus in contaminated soil or water can be fatal, and contaminated soil may cause mild chemical burns[31].

19.4.4.6 Insensitive Munitions

It is MOD policy to reduce the risks from UK munitions to levels that are either Broadly Acceptable or Tolerable and As Low As Reasonably Practicable (ALARP) by minimising the probability of inadvertent initiation and severity of subsequent collateral damage to weapon platforms, logistic systems and personnel when subject to unplanned stimuli. This is known as the Insensitive Munitions (IM) policy.

For warheads there are two main types of high explosive that are current candidates as having the necessary characteristics for filling IM munitions, polymer bonded explosives (PBX) and insensitive munitions explosives (IMX). The PBX explosives derive their IM characteristics from the physical properties imbued by the polymer matrix and include the familiar energetic materials RDX and HMX. The IMX explosives use more novel energetic materials such as 2,4-dinitroanisole (DNAN) and 3-nitro-1,2,4-triazol-5-one (NTO) which are both less sensitive to shock and heat than TNT and RDX[32].

Currently (2017) PBX materials are in common use in the UK, other European countries and extensively by the US Navy and US Air Force. The US Army now employ IMX-101 as a replacement for TNT, and IMX-104 in place of Composition B (RDX:TNT 60:40 % w/w). The environmental impact of these materials is still under investigation, but the current state of the art is summarised below.

19.4.4.7 Insensitive Munitions Explosives (IMX)

The two main IMX compositions currently in use in the US are IMX-101 (DNAN, NQ and NTO) and IMX-104 (DNAN, NTO and RDX). As with conventionally filled munitions only minimal explosive residues remain on a range after a high order detonation. In contrast, lower-order detonations may scatter up to 25 % of the energetics over a localized area, sometimes smaller than 100 m^2, [9, 33] and the residues may be of sufficient concentration to contaminate the soil and groundwater[34]. There is always a balance between providing an explosive that is more difficult to initiate from a safety perspective with the requirement of complete, reliable detonation.

RDX has been discussed in Section 19.4.4.1, and NQ in Section 19.4.4.3. NTO is more soluble than conventional explosives and will therefore dissolve more quickly in the environment[35]. NTO does not adsorb significantly to soil particles[36], although the rate of transport tends to be dependent on the soil pH, with adsorption decreasing as pH increases[37]. Laboratory studies have shown that NTO can be biodegraded[38], but the extent of biodegradation in the real environment is largely untested.

An additional concern with NTO is the acidity of aqueous solutions containing NTO, with the expectation that contaminated soil and water may exhibit increased pH known to cause leaching and migration of heavy metals in soil with low buffering capability. However, at the concentrations expected to be seen on ranges, no change in soil pH has been found[37].

NTO has low toxicity in mammals, but has been shown to cause reproductive toxicity in rats. In preliminary studies NTO has not shown significant aquatic toxicity and no water threshold levels have been identified.

DNAN is much less soluble than NTO (0.21 g L^{-1}), but does dissolve over time and has a low sorptivity to soil. DNAN therefore has the potential to quickly migrate into ground water[38]. Several microbial degradation products of DNAN have been identified that may adsorb to soil[39]. Further research by the same group indicated that although DNAN is more soluble than TNT, its hydrophilicity and tendency to form degradation products that sorb irreversibly to soil may make DNAN less harmful than TNT.

The environmental impact of these types of explosive has not yet been fully investigated despite their increasing use in munitions.

19.4.4.8 Polymer bonded explosives

In PBX munitions high explosives are used in combination with a polymer binder which encapsulates the explosive and improves the insensitivity profile of the material. In addition to a polymer binder, a small amount of plasticizer is usually added to the formulation to change the physical properties such as flexibility, the temperature at which the formulation becomes brittle and to permit easier processing[40].

It is generally thought that the polymer binder, which is not water soluble and slow to degrade, protects the explosive filling from environmental degradation. However, polymers are known to expand with increased temperature, and degrade when exposed to sunlight (UV) which may release the explosive filling- usually a nitramine explosive or ammonium perchlorate. Although the rate of release of explosive from a polymer matrix is slow under natural conditions, it should be noted that over time the encapsulated explosive will migrate into the soil, while the polymer is more likely to remain at the surface for much longer[41].

19.5 ASSESSING THE ENVIRONMENTAL IMPACT OF EXPLOSIVES USING PROJECT ORIENTED ENVIRONMENTAL MANAGEMENT SYSTEMS

The MOD has developed a bespoke platform known as the Project Orientated Environmental Management System (POEMS), which was designed to facilitate the application of an Environmental Management System (EMS) to specific MOD activities and equipment throughout the life cycle.

POEMS is based on the international standards ISO 14001 and ISO 14040, the former representing the cornerstone of an EMS and the latter covering life cycle assessment (LCA). LCA is a technique for assessing the environmental impact of a product throughout the entire lifecycle from extraction of raw materials to disposal, often referred to as ‘cradle to grave’. Table 19-5 gives an outline of the POEMS 9 core procedures for implementation.

Table 19-5 POEMS Core Procedures

EMP No.	EMP Title	EMP Overview
1	**Environmental Management Plan**	An Environmental Management Plan (EMP) is developed so that potential environmental aspects and impacts are defined at the early stages of a project. The EMP better enables Project Teams to manage environmental performance and apply appropriate resource and support so that effective environmental management can be implemented.
2	**Stakeholder Communications**	To ensure that environmental impacts are identified and appropriately managed, information on relevant stakeholders, their needs and possible contribution to the project should be collated and documented.
3	**Standards Identification and Demonstration of Compliance**	It is important to identify standards that apply to specific projects so that compliance can be demonstrated. Relevant standards should be recorded and adjusted accordingly throughout the life cycle of the project.
4	**Screening and Scoping**	The purpose of this procedure is to identify and detail relevant aspects, impacts and potential risks of the acquisition. This provides an opportunity to influence procurement and design decisions.
5	**Impact Priority and Evaluation**	This procedure provides guidance on how to prioritise environmental impacts as high, medium or low. This helps to decide what impacts take priority and if further assessment is required. In order to document this Environmental Features Matrix (EFM) is developed.
6	**Objectives and Targets**	This procedure represents the first step of the Environmental Impact Management process which will assist project teams to manage their medium and high environmental priorities. Objectives and targets can represent mitigating activity and should be recorded in the EFM.
7	**Environmental Impacts Management**	This procedure is to help project teams to appropriately manage their medium and high priority environmental impacts. It also requires teams to continue to document and act where appropriate in relation to their low priority and positive environmental impacts and produce appropriate environmental reports.
8	**Operational Controls**	Operational control exists to ensure an activity is completed in the correct/desired way. This procedure should assist project teams in identifying where operational controls are required and checking the adequacy of operational controls. An operational control represents a mitigating activity and should be recorded in the EFM.
9	**Continuous Review**	Continuous review should ensure that POEMS outputs are kept up to date with overall project and other developments. A review should be part of a planned process of revision as the project progresses in order to incorporate improved or amended information, or as the result of audit findings. This procedure assists the project team in continuous review and improvements to their projects

One of the most important elements of POEMS is the compilation of an environmental features matrix which ranks the environmental impacts in priority order to determine the most significant environmental impacts associated with a piece of equipment. The Environmental Features Matrix considers each activity in turn, considering whether it is normal (planned and usual), abnormal (planned but unusual) or unplanned. For each of the activities an associated environmental aspect is ascribed. An environmental aspect is a feature or characteristic of an activity, product, or service that affects or can affect the environment. Depending upon the nature of the environmental receptor there will be an environmental impact. An environmental impact is a change to the environment and such change can be positive or negative. To assess potential impacts each potential impact is scored in terms of its severity and frequency or duration. The scores are on a scale of 1 to 5 for frequency/duration and are cross-referenced with the severity scored from ‘a’ to ‘e’ (Figure 19-4). These scores are aligned to high, medium and low priority environmental risks. An example of an Environmental Features Matrix template is given at Appendix A.

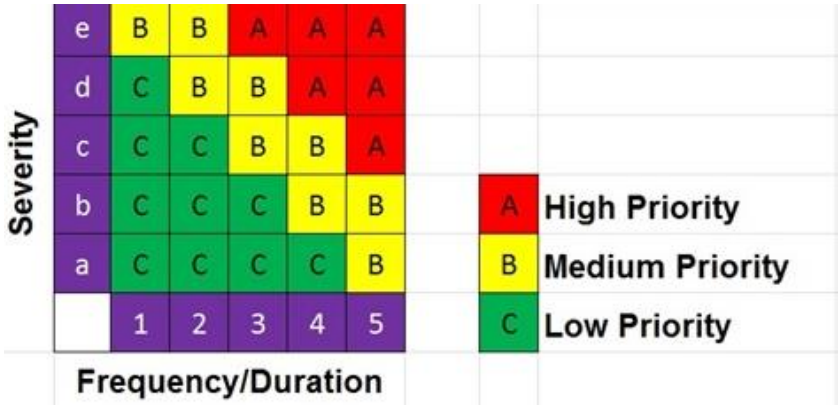

Figure 19-4 POEMS severity versus frequency and duration scoring matrix

The severity of an environmental impact is a measure of the degree of environmental damage that the impact represents. The lowest rating for severity is ‘Minor’ and the highest ‘Critical’. Frequency is defined as the number of times that the environmental impact is expected to occur, for example, once a week, once a day or once a year. The ‘duration’ is the length of time that the impact lasts for, for example, 30 minutes, 5 hours or continuous.

Once the methodology for priority evaluation is established, environmental impacts shall be prioritised using the categories chosen. The threshold score for further action is ‘B’ for medium priority impacts, with a higher threshold score of ‘A’ for high priority impacts. The two threshold levels are intended to give greater resolution between priority of impacts which require action and will assist the Project Team to make management decisions including whether or not to embark upon a full Environmental Impact Management (EIM) approach. Impacts scoring ‘C’ should not need any immediate further action. Further details of the POEMS process can be found through the Acquisition Safety and Environmental Management System website[42].

The Ministry of Defence issues guidance on environmental issues that need to be taken into consideration in the design and operation of land ranges. This guidance is given in JSP 403 ”Handbook of Defence Range Safety” Volume 2 Chapter 2 “Range Design Criteria and Specification” Paragraphs 02102 – 02104.

19.6 MONITORING AND SAMPLING

Where explosives are in constant use, and pathways to receptors have been identified, it may be necessary to monitor receptors for traces of contaminants, usually by taking several samples and submitting them for laboratory analysis. Monitoring of receptors can be continuous, or can be carried out at regular intervals. For ranges it is rarely necessary to conduct continuous monitoring, rather nearby receptors such as rivers, potable water sources or ground water may be tested regularly if there is a likely SPR linkage between the source and the receptor. Alternatively, if a contamination problem has been discovered by some other means for example illness in a nearby animal population, a sampling strategy may be required to identify the source, or the pathway of the contamination. Here the need for different sampling strategies depending on the objective of the investigation, and the different methods available for monitoring and sampling different environmental receptors will be considered.

The sampling method for a specific area will depend on the desired outcome of the project. For example the sampling method for determining average concentration of a contaminant across a site, may be different from a sampling method to determine contaminant hotspots. The sampling method will also differ between area size, and medium including land, surface water, ground water or ocean beds. It is possible to sample air quality, but for outdoor explosive ranges this is unlikely to be necessary due to the quick dissipation of small quantities of gases over large distances and so will not be considered.

19.6.1 Sampling Methods for Monitoring Processes

Monitoring can occur when the contamination, and contamination source is known. Monitoring programmes usually monitor air, soil or water for specific contaminants that have been identified as possible contaminants and that may be harmful to environmental receptors, including local populations.

Whilst some explosives have threshold levels for drinking or surface waters, there are no UK threshold limits for explosive contamination in soil, and the limits for some newer explosives have not yet been determined. A threshold level does not necessarily mean that the levels are completely safe, and often even if trace amounts are detected in drinking water measures will have to be taken to ensure the concentration decreases, or at the very least does not increase.

19.6.1.1 Monitoring water

Ground water tends to be inaccessible unless there is a nearby outflow such as a well or natural spring. For monitoring purposes it is likely that the receptor will

not be the groundwater itself, but will be nearby potable water sources, natural springs or rivers. In this case sampling will be conducted on a regular basis in the same way as surface water sampling would be conducted.

19.6.1.2 Sampling methods when investigating contamination

The main difficulty in investigating the source or extent of contamination is designing a representative sampling regime. The area under investigation may be very large so it can be difficult to choose which areas to sample, and how large a sample to take. When sampling land or water the depth of the collected sample also has to be considered, and whether the sample is taken at depth or is a cross section up to a specific depth. Some of these variables will be determined by the nature of the sampling area, and some will be determined by the objective of the investigation.

Another difficulty with sampling training ranges is the heterogeneity of deposited residues which can cause isolated hotspots. Detonation residues will be scattered over the range almost randomly, and will change depending on climate conditions, detonation method and the type of round detonated. Shrapnel will distribute differently to chemical and explosive residues, and when sampling an area it is likely that shrapnel, or even UXO's fall into the sampling area. It is usual to discard any large items when sampling soil or water as these are not representative of contaminants in the medium; however it is likely that there will be higher concentrations of certain contaminants around these items particularly in soil.

19.6.1.3 Soil sampling strategies

Multi-increment sampling is a sampling method developed to overcome the difficulties with obtaining representative sample of very large areas of heterogeneously deposited contamination. Instead of taking and analysing discrete samples which represent only a tiny portion of the entire area, multiple samples are taken and combined over several large areas of a range. Within one sample there may be up to 100 'increments', and each area is sampled up to three times to obtain three samples of up to 100 increments. Combining several sample increments increases the likelihood of identifying contamination, whilst eliminating heterogeneity by mixing samples. The protocol for sample collection and analysis is now well established, and has been shown to be highly repeatable. It has been identified as the recommended sampling method for many field studies, including some in the UK (Salisbury Plain Training Area, targeted land quality assessment document).

19.6.1.4 Surface and ground water

Ground water is usually sampled by drilling a series of boreholes and extracting water samples. To obtain a representative sample of groundwater it is first necessary to understand the hydrogeology of the area, mainly the extent of the ground water aquifer, so that samples can be taken from a representative area.

19.6.1.5 Ocean/ ocean bed sampling

Sea ranges present a particular problem for sampling and assessment of contamination due to the vast areas covered compared to land based ranges, the heterogeneity of firing patterns as there are no specific impact/firing areas and the natural currents that can move contamination and debris many thousands of miles. Localised contamination may occur near to sea dumping sites, but in general the first indication of a problem will be from impacts on the receptors, namely the aquatic flora and fauna.

Sampling for explosives in sea ranges is not available from the literature, but many other organic contaminants are monitored globally. One sampling method is the systematic sampling of large quantities of water, up to 1000 L at a time, using a technique called solid phase extraction in which contaminants can be adsorbed onto small fibres coated with a thin layer of polymer sorbent. Alternatively, discrete samples can be taken at intervals over the entire area and individually analysed for specific contaminants.

Often sampling oceans is not practically possible, but flora and fauna toxicity can be used as a good indication of a contamination problem. Local flora and deceased fauna can be analysed for indications of accumulation of the contaminant. This can be particularly useful for metals which are rarely metabolised.

19.7 RANGE MANAGEMENT

Prevention of contamination occurring is the preferred route for new site, and failing that a monitoring and mitigating programme that ensures legal compliance. However, for existing sites there will be contamination and remediation will be required at least upon vacation (see Section 6.4), or if a breach of legislation or a significant impact is identified.

Explosive contamination presents a particular problem in that there is rarely only one contaminant to remediate. As described in Section 19.4.4, the fate and transport is highly dependent on the chemical structure of the explosive, as well as the soil type and climate and so remediation techniques will have to be chosen for site specific problems, often several techniques will be required to ensure complete remediation[41].

19.7.1 Chemical Remediation

Chemical remediation techniques include in situ chemical oxidation (ISCO) remediation of matrices contaminated by explosives and other toxic aromatic compounds with nitro substituents. The pre-treatment step involves the injection or addition of a relatively inexpensive reducing agent (lactate or ethanol) which renders the contaminant more susceptible to conventional treatments such as with permanganate due to the conversion of one or more nitro substituents to an amine group. The pre-treatment step is applicable to soil and aqueous matrices.

19.7.2 Physical Remediation

The physical remediation of ground contaminated with explosives is referenced in the NATO Handbook on Reclamation of Contaminated Land Chapter 9-AVT197. This addresses the possibility of disposing of the contaminants in controlled fires. First combustible material in the form of dried plant material, wood chips, pine needles and the like are spread out in combination with glycerine and $KMnO_4$. This method has been shown to effectively reduce surface contamination of TNT and RDX[43]. The challenge is that a temperature of over 250 °C is required for the explosive to be completely combusted. A lower temperature results in the TNT melting and migrating to deeper soil layers. In practice only a soil depth of a few centimeters attained the required temperature therefore this method is only effective if the explosive is located on or very near the surface[43].

19.7.3 Biological Remediation

The NATO Handbook on Reclamation of Contaminated Land Chapter 9 covers phytoremediation methods utilizing plants to degrade explosive residues by three main principles, which can be used individually and in combination.

- Phytoextraction - uptake and concentration of the contaminants from soil and water into plant biomass
- Phytotransformation - explosives are transformed as a result of the plant metabolism, leading to the formation of a less toxic product, degradation, or immobilization
- Phytostimulation – introduction of a plant that has micro-organisms living in the root zone of the plant able to degrade the explosives. This is also called rhizodegradation

Explosives are taken up through the roots of the plant. It is considered that nitramines such as RDX are transported to the leaves, while nitroaromatics such as TNT are more likely to accumulate in the roots. In practice phytoremediation is difficult to implement because it involves identifying a plant that is appropriate to a particular site and type of contamination, which may in practice not be possible.

19.8 SITE REMEDIATION

Explosives manufacturers are continually improving manufacturing processes to meet today's changing technical, safety and environmental requirements. In making these improvements, buildings within a manufacturing facility may become obsolete and must be decommissioned in a safe and environmentally acceptable manner. At times an entire facility may be phased out requiring the decommissioning of numerous explosives-contaminated structures. The decommissioning of such a structure may present less obvious hazards. For example, processing buildings in which explosive materials have been managed may contain explosives residues hidden within cracks, crevices, under floorboards, in ventilation ducts or behind wall panels. Explosive

materials also may be present inside or in areas surrounding process machinery.

Decontamination of structures that have contained blasting agents composed of high percentages of water soluble, hygroscopic salts such as ammonium nitrate and fuels may be achieved by sweeping or other physical means. Water wash-down usually results in the safe decontamination of this building category. In certain cases, collecting and treating the wash-down water may be required. Open burning is not recommended for this explosives contaminated building category.

Decontamination of black powder and similar pyrotechnic mixtures may also be achieved by mechanical cleaning followed by water wash-down. However, due to the ease of ignition after drying, burning is recommended for this building category.

Water insoluble molecular explosives such as nitroglycerine, tetryl, TNT, PETN, RDX, and HMX require special decontamination and dismantling procedures. These procedures may include sweeping and physical removal followed by steam cleaning of equipment and the use of solvents, such as acetone, or a desensitising oil prior to the removal of threaded fittings. Trinitroresorcinol, lead styphnate, lead azide, mercury fulminate and other initiator explosives are sensitive to initiation by heat, impact and friction. These materials present the supplementary problem of residual metal contamination after the criteria of reactivity is eliminated. Structures that have contained these two groups of explosives require soil monitoring to assure complete, safe closure of the site. It is highly recommended that buildings used to manufacture or process any of these two groups of explosives be burned to eliminate possible hazards associated with reactive materials that may have accumulated in cracks, crevices or larger spaces within the floors and walls. When it is planned to burn out a building, excessive plastic, asphalt, or rubber materials should be removed and treated separately to minimize heavy soot production and the associated environmental nuisance. Detonations of below-ground liquid explosives in underground drains have been known to occur hours after initiation of the fire, therefore a 48 hour waiting period before approaching the site is recommended.

The burning out of old explosives facilities carries with it potential risks to both human receptors and environmental receptors from the deposition of air borne particulates; these deposited materials could affect both soil and surface water bodies in the area surrounding the burn site. These might include nitrous oxide, carbon monoxide, asbestos, lead vapours and particulates, zinc, poly-aromatic hydrocarbons, and dioxins.

19.8.1 Remediation of contaminated soil

Historically at some explosives manufacturing facilities explosives wastewater was collected in washout pools or lagoons which accumulated contamination in the soil which subsequently migrated into underground aquifers. Explosives also entered the soil during transport and storage on the site. The chosen

method to deal with this explosives-contaminated soil has been the use of a rotary kiln incinerator. In rotary kiln incineration soils are fed into a primary combustion chamber or rotary kiln where organic constituents are destroyed. The temperature of the gases in the primary chamber ranges from 450 ^{o}C to 650 ^{o}C, and the temperature of the soil ranges from 350 ^{o}C to 450 ^{o}C. Retention time in the primary chamber, which is varied by changing the rotation speed of the kiln, is approximately 30 minutes. Off-gases from the primary chamber pass into a secondary combustion chamber, which destroys any residual organics. Gases from the secondary combustion chamber pass into a quench tank and thence through a venturi scrubber and filters which remove acid gases and particulates prior to release from the stack. The treated product of rotary kiln incineration is treated soil which drops from the primary combustion chamber after organic contaminants have been destroyed. This product is routed into a wet quench or a water spray to re-moisturise it, then transported to a storage area.

The process is not without environmental concerns. The incinerator requires a large amount of fuel to produce the required heat and a powerful fan for air flow. There also is an attendant noise problem. Nevertheless the technique can achieve a 99.99 % destruction of explosives residues.

19.9 COMPUTER MODELLING AND ENVIRONMENTAL DATABASES

19.9.1 Computational modelling for predicting fate and transport

Computer models are commonly used to attempt to predict SPR linkages for explosives, and estimate the environmental risk for lifecycle assessment (LCA) or environmental management systems (EMS).

Environmental toxicity models use mathematical approaches to combine different forms of data, such as toxicological data and characteristics of the environment, into concise information suitable for environmental risk assessment, or to determine contamination levels in an area or environment. The typical inputs and outputs of an environmental toxicity model are summarized in Figure 19-5.

Several different modelling tools can be used to investigate the environmental impact of exposure to chemical contaminants. Fate and transport models are well-established tools that characterise the behaviour of contaminants in the environment. Fate and transport models have been parameterised at different spatial resolutions and can be used for either steady-state calculations (constant over time events or assumptions) or transient calculations (accounting for changes over time)[44]. The parameterisation of fate and transport models already encompasses factors such as temperature, rainfall, atmospheric circulation patterns, and degradation pathways[44–50].

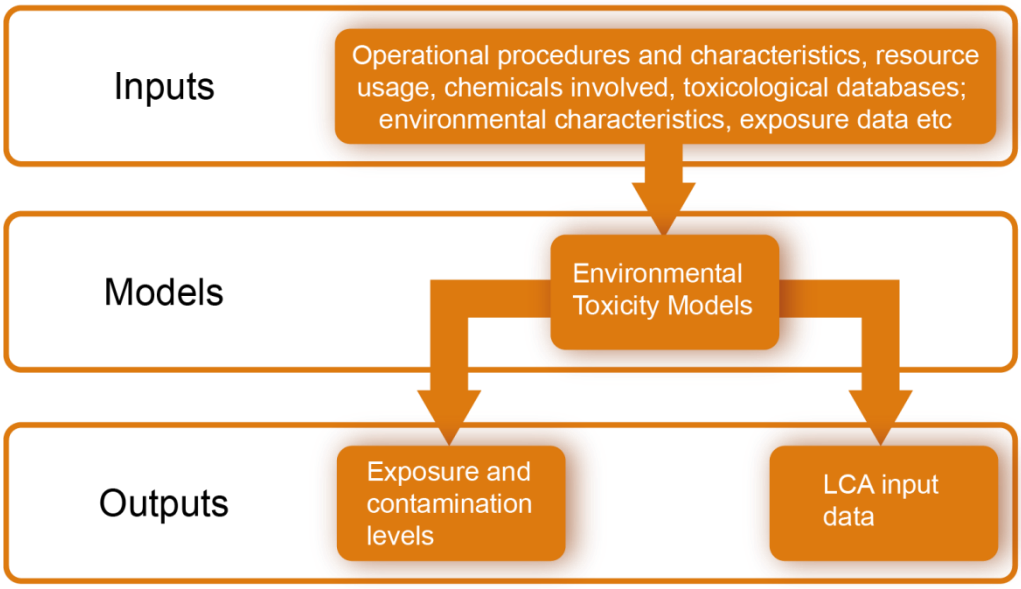

Figure 19-5 Inputs and outputs in an environmental toxicity model

Fate and transport models produce dispersion-related data and must be coupled with other tools, such as environmental toxicity models, in order to fully understand the environmental issues that are compiled in an Environmental Impact Assessment (EIA) document. Therefore, the selection of a toxicity model plays a significant role in the overall EIA. In many cases the input data is available in databases, and are compiled from both experimental and predicted data.

Environmental modelling can be a very powerful tool when used to assess a specific, well defined problem. However, there are many different environmental modelling tools available which must be carefully chosen to suit the problem. In all cases the limitations and assumptions of the chosen environmental model must always be taken into consideration.

19.9.2 Information Databases

Some countries have developed databases of information for range management and munition disposal. One example is the Norwegian Defence Environmental Database (NDED) which is used to log ammunition usage on small arms ranges in order to calculate accumulation of specific contaminants[51].

The MIDAS Program was developed in 1992 by the U.S Department of Defence to identify alternatives to open burning/open detonation (OB/OD), and to provide a systematic approach to the disposal of unwanted munitions[52]. The system has gone through several updates and is now known as “Web-based Munition Automated Environmental Analytical Capabilities.” The updated suite covers risk assessment, water dispersion and deposition, the permit repository and assets and more.

Although not specifically for munitions, The University of Rhode Island has an Explosives Database, funded through the auspices of the National Memorial Institute for the Prevention of Terrorism. The database is an interactive library of analytical data for explosive and energetic compounds arranged by name, and analytical technique[53]. At the current time, the UK does not have an established environmental database for munitions but relevant research is undertaken when required.

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Appendix A Environmental Features Matrix

Table 19-6 Environmental Inputs

EMP04/F/01 – Environmental Feature Matrix										
In-Service										
Embodied Materials and Energies (Inputs)							**Priority Assessment**			Mitigation
Activity	Normal/ Abnormal/ Emergency	Aspect (Materials and Energies	Receptor	Impact	Positive/ Negative	Impact Codes	Severity	Frequency/ Duration	Priority Score (A, B, C)	Controls
Detonation upon target	Normal	Detonation of explosives	Land	Non-Renewable Resource Use	Negative	NR	b	3	C	
Functioning of gun at launch site	Norma	Burning of propellant	Land	Non-Renewable Resource Use	Negative	NR	b	3	C	

Table 19-7 Environmental Outputs

Emitted Materials and Energies (Outputs)							Priority Assessment			Mitigation
Activity	Normal/ Abnormal/ Emergency	Aspect (Materials and Energies	Receptor	Impact	Positive/ Negative	Impact Codes	Severity	Frequency/ Duration	Priority Score (A, B, C)	Controls
Detonation upon target	Normal	Noise	Humans	Nuisance	Negative	N	b	3	C	
Detonation upon target	Normal	Shell fragments	Humans	Human Health	Negative	H	b	3	C	
Detonation upon target	Normal	Lead fumes from fuze	Humans, Land, Air, Water	Human Health,	Negative	H, L, A, Wat	c	3	B	
Detonation upon target	Normal	Gaseous products	Humans, Air	Human Health, Air Pollution	Negative	H, A	b	3	C	
Firing the gun – launch site	Normal	Noise	Humans	Nuisance	Negative	N	b	3	C	
Functioning of gun at launch site	Normal	Lead fumes from propelling charge	Humans, Land, Air, Water	Human Health	Negative	H, L, A, Wat	c	3	B	